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SERVO SYSTEM OF COMBINE CONTROL, (U)  
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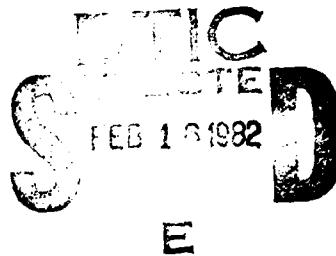
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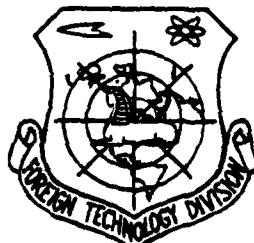
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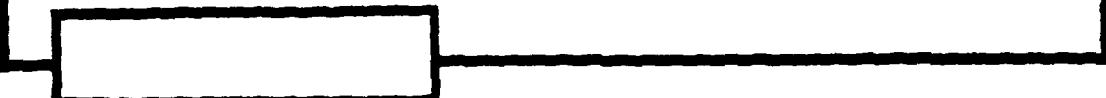
SERVO SYSTEM OF COMBINE CONTROL

by

B.V. Novoselov, A.A. Kobzev, et al



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Б б	Б б	В, в	С с	С с	С, с
В в	В в	В, в	Т т	Т т	Т, т
Г г	Г г	Г, گ	Ү ү	Ү ү	Ү, ү
Д д	Д д	Д, д	Ф ф	Ф ф	Ф, ф
Е е	Е е	Ye, ye; Е, е*	Х х	Х х	Kh, kh
Ж ж	Ж ж	Zh, zh	Ц ц	Ц ц	Ts, ts
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О о	О о	O, o	Խ խ	Խ խ	Yu, ju
Ո ո	Ո ո	P, p	Յ յ	Յ յ	Ya, ya

\*Use initially, after vowels, and after в, ә, е elsewhere.  
When written as ё in Russian, transliterate as ѿ or ё.

RUSSIAN AND ENGLISH TRIGONOMETRIC FUNCTIONS

Russian	English	Russian	English	Russian	English
sin	sin	sh	sinh	arc sh	sinh <sup>-1</sup>
cos	cos	ch	cosh	arc ch	cosh <sup>-1</sup>
tg	tan	th	tanh	arc th	tanh <sup>-1</sup>
cotg	cot	cth	coth	arc cth	coth <sup>-1</sup>
sec	sec	sch	sech	arc sch	sech <sup>-1</sup>
cosec	csc	csch	csch	arc csch	csch <sup>-1</sup>

Russian      English

rot	curl
lg	log

## SERVO SYSTEM OF COMBINE CONTROL

B.V. Novoselov, A.A. Kobzev, Yu. S. Gorokhov, G.A. Balabolov, and  
A.M. Potapov

The invention refers to automatic control systems and can be used in the design of high-current servo systems when there is harmonic noise in the input signal.

Well-known are servo systems of combined control which contain the basic control circuit and two differentiators of the compensator [balancer].

Let us assume, for example, that we have transfer functions of the basic circuit

$$K(p) = \frac{K}{T_1 p^4 + T_2 p^3 + T_3 p^2 + p}$$

and differentiator

$$\begin{aligned}\dot{\varphi}_1(p) &= K_1 p, \\ \dot{\varphi}_2(p) &= \frac{1 + T_4 p}{1 + T_5 p}; \quad z = \frac{T_4}{T_5},\end{aligned}$$

where  $p$  is the complex variable;  $T_4$  and  $T_5$  - the time constants;  $T_1$ ,  $T_2$ , and  $T_3$  - the coefficient constants; and  $K$  and  $K_1$  - the gain constants.

In the reproduction of the input action  $\theta_1$  (VV), the error of the system can be presented in the form

$$\theta = \theta_x + \theta_s + \theta_v + \theta_n,$$

where  $\theta_k$  is the error proportional to the speed of the VV;

$\Theta_A$  - the error proportional to the acceleration of the VV;  $\Theta_y$  - the error proportional to the higher derivative of the VV; and  $\Theta_n$  - the error caused by the noise at the input.

With the reproduction of the VV of forms

$$\Theta_1(t) = \Omega_1 t; \Theta_2(t) = \frac{\Omega_1^2}{2} t^2; \Theta_3(t) = \Theta_{1m} \sin \omega_1 t \quad (1)$$

for the compensation of  $\Theta_k$  and  $\Theta_A$  it is necessary to select parameters of the compensators from conditions

$$K_A = \frac{1}{K}, \quad T_A = T_1 + T_2.$$

Here it is possible to ensure the compensation at different values of  $T_5$ .

With the reproduction of the sinusoidal useful signal with the harmonic noise superimposed on it

$$\Theta_1(t) = \Theta_{1m} \sin \omega_1 t + \Pi_m \sin \omega_m t, \quad (2)$$

where  $\Theta_{1m}$  is the amplitude value of the useful VV;  $\Pi_m$  - the amplitude value of the noise;  $\omega = \frac{2\pi}{T}$  - the circular frequency of the useful VV;  $T$  - the period of the useful VV,  $f = 1/T$ ;  $\omega_n = \frac{2\pi}{T_n}$  - the circular frequency of the noise;  $T_n$  - the noise period,  $f_n = \frac{1}{T_n}$ ,  $f_n > f$ , and in the system the noise is determined by the reproduction of the useful VV and noise  $\Pi(p)$ :

$$\Theta(p) = \Phi_e(p)\Theta_1(p) - \Phi(p)\Pi(p),$$

where  $\Phi_e(p) = \frac{1 + \varphi(p)K(p)}{1 + K(p)}$  is the transfer function of the closed error system;  $\Phi(p) = \frac{1 - \varphi(p)K(p)}{1 + K(p)}$  - the transfer function of the closed system;  $\varphi_p$  - the transfer function of the compensator.

In the use of the equivalent transfer function of the open system  $K_e(p)$ , the error is expressed thus

$$\Theta(p) = \frac{1}{1 + K_e(p)} \Theta_1(p) - \frac{K_e(p)}{1 + K_e(p)} \Pi(p) \\ \Pi(p) = \Theta_n(p) + \Theta_\phi(p),$$

where  $K_e(p) = \frac{\varphi(p)}{1 - \varphi(p)}$ ;

$\Theta_\phi(p)$  is the error from the useful VV; and  $\Theta_n(p)$  - the error caused by the noise.

An important shortcoming of servo systems of combined control (SSKR) is the fact that, by ensuring the minimal errors in the reproduction of the input action of forms (1), they have a great error when superimposed on it is harmonic noise of the form  $\Pi(t) = \Pi_m \sin \omega_n t$ , and also increased oscillating nature with the development of jumps in the angle and speed

$$\Theta_1(t) = I(t), \Theta_1(t) = \frac{I^t}{2}.$$

The purpose of the proposed invention is to minimize errors both with the VV of form (1) and in the case when the VV is superimposed by the harmonic noise

$$\Pi(t) = \Theta_{1m} \sin \omega t,$$

and also to decrease the oscillating nature with development of the VV in the form

$$\Theta_1(t) = \pi_1 t + \text{const},$$

$$\Theta_1(t) = I(t) \quad (3)$$

Let us examine the conditions in which the error from the useful VV will be minimal

$$\Theta_{\epsilon}(p) = \frac{1}{1 + K_s(p)} \Pi_1(p).$$

or in the domain of the complex variable  $j\omega$ ,

$$\Theta_{\epsilon}(j\omega) = \frac{1}{1 + K_s(j\omega)} \Theta_1(j\omega);$$

since  $\Theta_k$  and  $\Theta_A$  are compensated by the appropriate selection of parameters of the compensators ( $K_s(j\omega) = \frac{1}{K} \cdot T_s = T_s + T_s$ ), then present in the system will be errors caused by the higher derivatives of VV. If  $\omega < 1$ , then  $|K_s(j\omega)| \gg 1$ . and the maximal error  $\Theta_{\epsilon_{\max}}$  can be presented in the form

$$\Theta_{\epsilon_{\max}} = \frac{1}{|K_s(j\omega)|} \Theta_{1_{\max}},$$

but since

$$\Theta_{1_{\max}} = \frac{\Pi_{1_{\max}}}{\omega},$$

(where  $\Pi_{1_{\max}}$  is the amplitude value of speed of the VV), then

$$\Theta_{\epsilon_{\max}} = \frac{\Pi_{1_{\max}}}{\omega |K_s(j\omega)|}.$$

From the last expression it follows that for a decrease in  $\Theta_{\epsilon_{\max}}$ , it is necessary to increase  $|K_s(j\omega)|$ . If  $\omega$  is changed in small

limits, then the increase  $|K_s(j\omega)|$ , for the retention of the error or its decrease with a change in  $\pi_{17}$ , must be conducted proportional to  $\pi_{17}$ .

The component of the error caused by noise in the domain of the complex variable  $j\omega$  has the form

$$\Theta_n(j\omega) = \frac{K_s(j\omega)}{1 + K_s(j\omega)} \Pi(j\omega).$$

When the noise frequency  $\omega_n \gg 1$ , then  $K_s(j\omega) \ll 1$ , and the error from the noise can be presented as

$$\Theta_n(j\omega) = K_s(j\omega) \cdot \Pi(j\omega)$$

or

$$\Theta_n = |K_s(j\omega)| \Pi,$$

i.e., the less  $|K_s(j\omega)|$ , the less the error from the noise.

We can find the expression of the minimum  $|K_s(j\omega)| = \min$  as functions of  $T_5$ .

To do this, it is necessary to differentiate with respect to  $T_5$  twice. As a result, we get

$$|K_s(j\omega)| \xrightarrow{\text{differentiate}} 0 \xrightarrow{\text{differentiate}} T_5 \rightarrow \infty.$$

Consequently, by increasing  $T_5$ , we can decrease the error caused by the noise. It is completely clear that with an increase in the noise it is necessary to increase the time constant  $T_5$  of the compensator in order that the second derivative of the noise does not pass into the system. With an increase in the noise frequency, it is possible without a loss to decrease  $T_5$ . However, in this case for the compensation of errors proportional to the speed and acceleration of the VV, it is necessary to retain conditions of their compensation.

With the reproduction of the useful VV with the noise (2) superimposed on it, the errors caused by the speed and acceleration of the VV are compensated appropriately by the selected parameters of the compensators

$$\left( \text{in the given case } K_s \alpha = \frac{1}{K}, T_4 = T_3 + T_5 \right).$$

For the compensation of errors proportional to the higher derivative,

it is necessary to decrease the time constant of the compensators proportional to the amplitude value of the speed of the useful VV, but, on the other hand, to decrease the error caused by the noise, it is necessary to increase  $T_5$  with a decrease in the noise frequency, preserving the conditions of compensation of  $\Theta_k$  and  $\Theta_a$ . Consequently, to ensure the minimal error from the higher derivatives and the noise, the change in  $T_5$  must be conducted as a function of the relationship of  $\pi_1 \tau$  and  $\omega_n$ , i.e.,  $\theta_s + \theta_n = \min = f_2(\pi_1, \omega_n) = f_2(T_5)$ , necessarily preserving here the conditions of the compensation of  $\Theta_k$  and  $\Theta_a$ , and thus with a change in  $T_5$  it is necessary simultaneously to change  $\alpha$  in order that  $T_1 = T_3 + T_5$  and  $K_1\alpha = \frac{1}{K}$ .

With the reproduction of the useful VV with the noise superimposed on it of the form

$$\begin{aligned}\theta_1(t) &= \pi_1 t + \Pi_1 \sin \omega_n t, \\ \theta_2(t) &= \frac{\pi_1 t^2}{2} + \Pi_2 \sin \omega_n t\end{aligned}$$

present in the system will be errors

$$\theta = \theta_s + \theta_n \quad \text{in the first case}$$

and

$$\theta = \theta_s + \theta_n \quad \text{in the second case.}$$

Compensation of the errors  $\Theta_k$  and  $\Theta_a$  is ensured owing to the introduction of compensating signals proportional to the 1st and 2nd derivatives of the VV and the selection of parameters of the compensators from conditions  $\theta_s = 0$  and  $\theta_1 = 0$ . To decrease  $\theta_n$ , as was shown above, it is necessary to change the value of the time constant of the compensator  $T_5$ , preserving here conditions of compensation  $\Theta_k$  and  $\Theta_a$ , i.e., with a change in  $T_5$  it is simultaneously necessary to change  $\alpha$  in order that  $K_1\alpha = \frac{1}{K}$ ;  $T_1 = T_3 + T_5$ .

Furthermore, in the SSKR with the VV of the form (3), entering into the main circuit will be additional boosting signals owing to the presence of the compensators

$$\text{when } \theta_1(t) = i(t) \quad \theta_{\text{boost}}(t) = \varphi f(t) + \varphi' \frac{df(t)}{dt},$$

$$\text{when } \theta_1(t) = i\pi t \quad \theta_{\text{boost}}(t) = \varphi' \delta(t) \pi_1,$$

where  $\delta(t)$  is the pulse characteristic;

$$\varphi = K_a \cdot \varphi_1 = \left(1 - e^{-\frac{t}{T_5}}\right),$$

which will cause an increased oscillating nature. To decrease the increased oscillating nature in these cases, it is necessary to decrease the level of boosting signals because of the considerable increase in the time constant of the compensators  $T_5$  and defined moments of time.

The proposed device differs from the well-known devices in that additionally installed in it is a self-tuning unit the output of which is connected to the inputs of both differentiators, one of the inputs is connected with the output of the first differentiator directly, and the other input is connectrd through a key.

Furthermore, the system is distinguished by the fact that additionally installed in it is a second low-frequency filter, connected with the output of the compensator, and a third differentiator, conncted to the filter's output, and the output of the differentiator is connected with the input of the key; and additionally installed also is a relay unit connected with the second differentiator of the compensator and one more differentiator, which is connected with the input of the relay unit, <sup>and</sup> the input this differentiator is connected with the output of the first differentiator.

A block diagram of the servo system is given on the drawing.

The input of the main control circuit 1 with the transfer function  $K(p)$  is connected with the output of the compensator 2 with the transfer function  $\varphi(p)$ , which consists of two series connected differentiators 3 with the transfer function  $K_1 p$  and 4 with the transfer function  $\frac{1+T_1 p}{1+T_0 p}$ . The circuit of self-tuning 5 consists of a low-frequency filter 6, which passes the useful signal, the output of which is connected with the measuring and amplitude stor- age circuit 7; and a filter of upper frequencies 8, which passes noise, the output of which is connected with the frequency measuring circuit 9. The outputs of circuits of the measuring and storage of amplitude 7 and frequency measurement 9 are connected through scale devices 10 and 11 correspondingly with the summator 12. The output of the summator 12 is connected with the input of the relay

amplifier 13, the output of which is connected with the input of the power amplifier 14, and the output of the latter, in turn, is connected with the step-by-step switch 15. Furthermore, the circuit of self-tuning 5 includes a timing oscillator 16, which is connected with a power amplifier 14. The input of the filter of upper frequencies 8 is connected with the output of the differentiator 3, connected with which also is the input of the low-frequency filter 6 through key 17. The output of the self-tuning circuit 5, i.e., the output of the step-by-step switch 15 (moving contact), is connected with differentiators 4 and 3 and also with the summator 12. The input of the differentiator 18 is connected with the output of differentiator 3, and the output - with the relay unit 19, which is connected with the differentiator 4. The input of the differentiator 20, through the second low-frequency filter 21, which passes the useful signal, is connected with the output of the differentiator 4, and the output of differentiator 20 is connected with the key 17.

When tracking at a constant rate or constant acceleration, the signal is absent when there is no noise at the output of the high-frequency filter 8 and, consequently, at outputs of the circuit to measure frequency 9 and the scale device 11. At the output of the scale device 10 the signal is also absent, since the circuit of the differentiator 3 and low-frequency filter 6 is opened by key 17, because at the output of the differentiator 20, which generates the signal proportional to the 3rd derivative of VV, when tracking at a constant rate there is no signal, and when tracking with a constant acceleration there will be a signal  $T_5 L_3$  caused by the delay in the differentiator 4 (time constant  $T_5$ ) and insufficient for the triggering of the key 17.

The self-tuning circuit 5 changes neither the parameters of the summator 12 nor the parameters of differentiators 3 and 4, and the conditions of compensation of errors  $\Theta_k$  and  $\Theta_A$ , proportional to the rate and acceleration of the VV, are fulfilled. When there is a high-frequency harmonic noise, superimposed on the useful signal, at the output of the high-frequency filter 3 there will be a voltage which is proportional to the frequency and speed of the noise, and at the output of the frequency measuring circuit 9 and, consequently,

at the output of the scale device 11 there will be a signal which is inversely proportional to the noise frequency. The signal with the scale device 10 is absent, since the noise does not pass through the low-frequency filter 21 into the input of the differentiator 20, and the key 17 is opened.

At the output of the summator 12 there will be a signal which is proportional to the noise frequency, which, in being amplified in amplifiers 13 and 14, enters into the step-by step switch 15, which changes the position of its output magnitude by an angle proportional to the output magnitude of the summator with the operating frequency of the timing oscillator 16, changing the parameters of the differentiators 3 and 4 (by increasing the time constant  $T_5$  of the differentiator 4, i.e., increasing the degree of filtration of the noise and simultaneously changing the coefficient  $\alpha$  of the differentiator 3, which ensures the retention of conditions of the compensation of errors  $\Theta_k$  and  $\Theta_A$  ).

With turning at a definite angle proportional to the noise frequency, due to the presence of feedback from the output of the step-by-step switch 15 to the summator 12, the moving contact of the step-by-step switch 15 is stopped. As a result, the parameters of the compensator 2 are changed in such a way that a minimal error from the noise is ensured, and that conditions of the compensation of the steady-state errors  $\Theta_k$  and  $\Theta_A$  are retained.

With the reproduction of the sinusoidal useful VV with the high-frequency harmonic noise, the system operates in the following manner. At the output of the differentiator 20 there will be a signal from which the key 17 triggers, connecting the low-frequency filter 6 to the output of the differentiator 3. A signal of the speed of VV and speed of the noise is fed to inputs of filters of low frequencies 6 and upper frequencies 8. A signal proportional to the amplitude value of the rate of the useful VV is formed at the output of the amplitude storage circuit 7 and, consequently, at the output of the scale device 10. A signal which is inversely proportional to the noise frequency is formed at the output of the frequency measuring circuit 9 and, consequently, at the output of the scale device 11. From output of scale devices 10 and 11 the signals

are fed to the summator 12, at the output of which there is formed the signal proportional to the algebraic difference in the amplitude value of the speed of the useful VV and frequency of the noise superimposed on it.

Subsequently, the self-tuning circuit operates similarly. As a result of the change in the parameters of the compensators, the minimal error with the given ratio parameters of the useful VV and noise is ensured in the system.

In the absence of noise the step-by-step switch 15 changes the position of its output magnitude by an angle proportional to the amplitude value of the rate of VV, changing the parameters of the differentiators 3 and 4 in such a way that retained are conditions of compensation  $\Theta_k$  and  $\Theta_d$  and the error, minimally possible for this system, from higher derivatives of the input action.

In the development of the jumps in the angle and rate, the differentiator 18 generates a pulse from which there is a triggering of the relay unit 19 for the time of  $t = 0.2$  s, and it changes the parameters of the differentiator 4 (significantly increasing its time constant and decreasing the transmission coefficient); and as a result of this the boosting pulse only partially passes into the main circuit 1, thereby decreasing the oscillating nature of the SSKR.

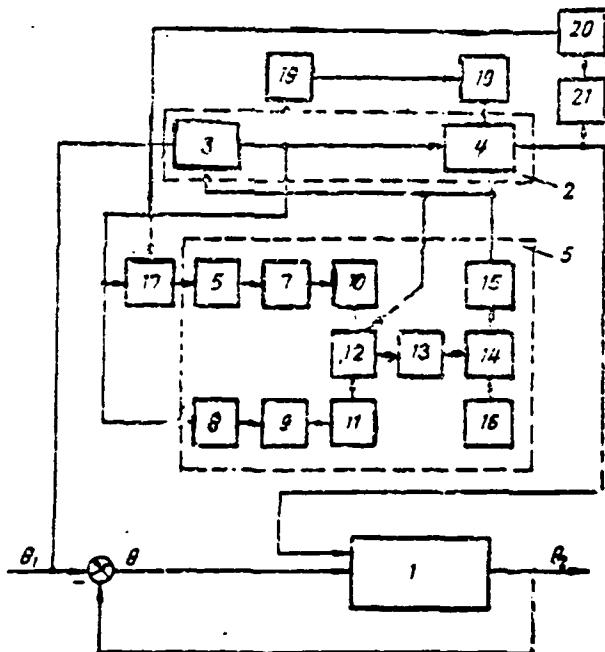
#### Object of the invention

1. A servo system of combined control, which contains a basic control circuit and two differentiators of the compensator, which is distinguished by the fact that for the purpose of decreasing the errors with reproduction of the sinusoidal input action both with high-frequency harmonic noise superimposed on it and without it; additionally installed in it is a self-tuning unit, the output of which is connected to the inputs of both differentiators, and one of the inputs is connected with the output of the first differentiator directly and the other input, through a key.

2. A system according to item 1, which is distinguished by the fact that for the purpose of decreasing the error when tracking with a constant rate or acceleration in the presence of a high-frequency

harmonic noise, additionally installed are a second low-frequency filter, connected with the output of the compensator, and a third differentiator, connected to the filter's output, the output of which is connected with the input of the key.

3. A system according to item 1, which is distinguished by the fact that for the purpose of decreasing the oscillating nature with the development of jumps in the angle and rate, additionally installed are a relay unit, connected with the second differentiator of the compensator, and a differentiator, which is connected to the relay's input, the input of which is connected with the output of the first differentiator.



Block diagram

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